String Theory and Cosmological Singularities

Cosmo-02

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Based on H. Liu, G. Moore and N.S.

Related Works: Lawrence; Martinec, and McElgin; Fabinger and McGreevy; Horowitz and Polchinski

String Theory and Cosmology

For a theory of the Big Bang and early Universe we need to go beyond general relativity. In string theory

$$L = g_{string}^{-2}\, \alpha'^{-1}(R+\alpha' R^2+\ldots) +\ldots$$

$$\alpha' = M_{string}^{-2}$$

We have a double expansion in:

$$\text{Energy}^2\, \alpha' \quad \text{and} \quad g_{string}^{\,2} = \hbar$$

For $R \sim m_{string}^{\,2}$ or $m_{planck}^{\,2} = g_{string}^{-2}\, m_{string}^{\,2}$ all higher order terms are equally important. Need to treat exactly

Hope

- String theory will lead to a detailed theory of the Big Bang
- Experimental tests of string theory

String Theory and Singularities

Double expansion in

Energy^2 α' and $g_{string}^2 = \hbar$

Can a singularity in general relativity be smooth in classical string theory ($g_{string}^2 = \hbar \ll 1$)?

Or is it smooth only in the quantum theory?

Example I: Orbifolds

- $x \sim -x$

- $(x_1, x_2) \sim (-x_1, -x_2)$ 2d cone

- $(x_1, x_2, x_3, x_4) \sim (-x_1, -x_2, -x_3, -x_4)$

  A_1 singularity (hard to draw)

Orbifolds (cont.)

- General relativity is singular but classical string theory is smooth!
- In some cases (with supersymmetry) even the quantum corrections are smooth

Example II: Conifold

It turns out that the A_1 orbifold

$$(x_1, x_2, x_3, x_4) \sim (-x_1, -x_2, -x_3, -x_4)$$

can be deformed. Not visible in GR

There is a small (zero size) two-sphere at the singularity and a certain flux ($B_{\mu\nu}$) can pass through it

The orbifold corresponds to a certain nonzero flux

For Flux = 0

- Classical general relativity is singular
- Classical string theory is singular
- Quantum string theory is regular. But it is not described by the degrees of freedom which are visible in the classical theory. Need new degrees of freedom

Question

Is the cosmological singularity smoothed by

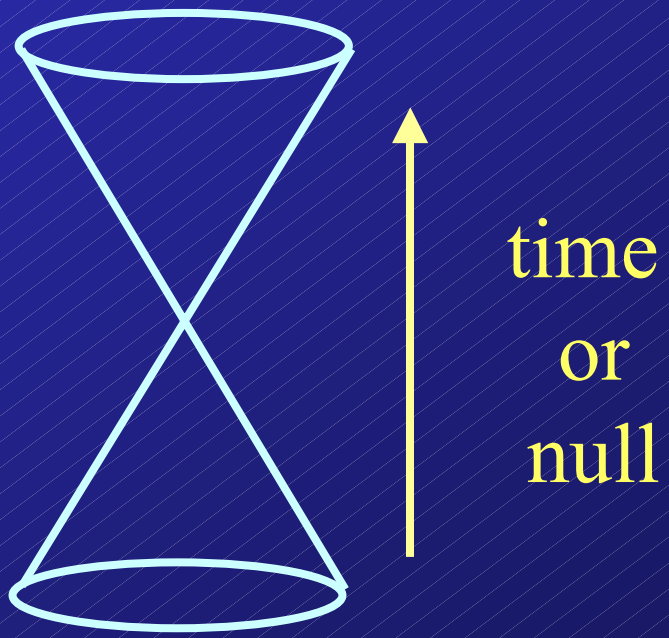
I. classical string theory, or

II. quantum string theory?

New challenge: time dependent problem

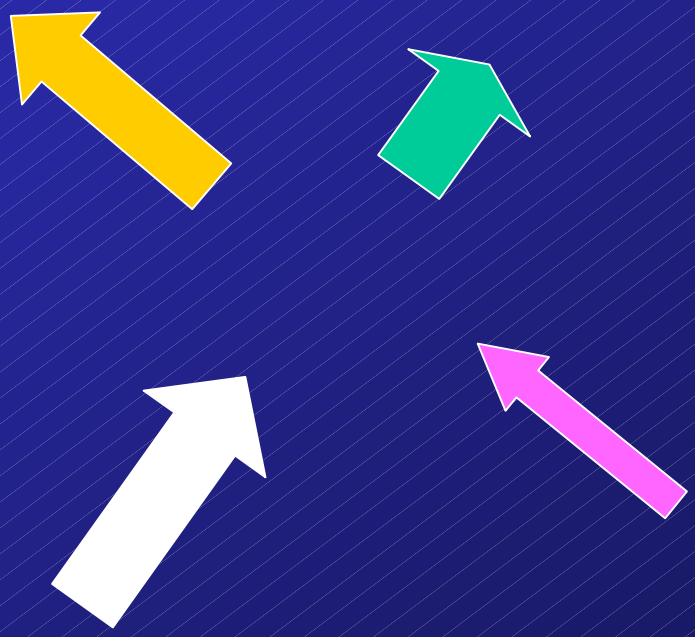
Toy Model of the Big Bang

- Solution of the classical string equations of motion (not only GR)
- The Universe contracts and expands
- Same singularity in certain black holes (a closely related problem)



Observables: S-matrix

Start in the far past with some particles (small fluctuations). Compute the amplitude to find other particles (other small fluctuations) in the far future.



Results

- For generic kinematics the amplitudes in classical string theory are finite (while they diverge in GR)
- For special kinematics (near forward scattering) the string amplitudes diverge

Origin of the Divergence

Since the background depends on time, energy is not conserved, and particles do not have fixed E

Incoming particles are accelerated (blue shifted by the contraction)

The energy is infinite near the singularity, and hence divergence in the amplitudes

Lessons

- Classical string theory is singular in time dependent singular orbifolds
- These classical solutions are unstable
- Need to understand the full quantum theory to explain the physics at the singularity

What About the Ekpyrotic/Cyclic Model?

The suggestion that the Universe passes through the singularity is motivated by the orbifold construction - solution of the classical equations of motion.

We now see that classical string theory is singular and cannot be trusted.

The Cosmological Singularity Alternative Suggestions

- Beginning of time
  - Need initial conditions, wave function of the Universe, etc
- Time has no beginning or end
  - Need to understand how to pass through the singularity
- None of the above

Need New Ideas